Paper Title Exploring the Potential of a Mobile Augmented Reality Application to Teach Structural Analysis

Author(s) Aliye Karabulut Ilgu, Iowa State University; Elizabeth Miller, Iowa State University; An Chen, Iowa State University; Rafael Radkowski, Iowa State University; Charles Jahren, Iowa State University; Yelda Turkan, Oregon State University; Amir Behzadan, Texas A&M University - College Station

Session Title Undergraduate Instruction and Experiences in Engineering and Computer Science

Session Type Paper

Presentation Date 4/20/2020

Presentation Location Online

Descriptors Instructional Interventions, Technology

Methodology Quantitative

Unit Division C - Learning and Instruction

DOI https://doi.org/10.3102/1580944

Exploring the Potential of a Mobile Augmented Reality Application to Teach Structural Analysis

Objectives

Structural Analysis is an introductory course for structural engineering, taught in every undergraduate civil, construction and architectural engineering program. Despite its crucial role in the curriculum, most students taught in this course do not appear to have a sound understanding of the fundamental concepts. In particular, students lack the ability to visualize the deformed shape and predict the effects of loads on simple structures, a necessary skill to conceptualize structural behavior beyond theoretical formulas and methods (Davalos, Moran, Kodkani, 2003; Teng, Song, & Yuan, 2004). To address this learning problem, a mobile and interactive augmented reality (AR) application was developed and implemented in a junior level structural analysis course at a large midwestern university. A quasi-experimental study was conducted to assess the effectiveness of AR compared to traditional lecture style. The preliminary results of the experiment, classroom observations, and student perspectives will be reported in this proposal.

Perspectives

AR combines the real world with the virtual content so that it conserves users' awareness of the real-world environment in a 3D space (Azuma et al., 2001). It enables users to visualize virtual objects and to interact with both real and virtual objects in the same context (Quarles, Lampotang, Fischler, Fishwick, & Lok, 2008) thus extending their perception of the real world (Wursthorn, Coelho, & Staub, 2004). AR has been integrated into the mainstream of a variety of STEM fields both at the operational and training levels; such as medical training (Quarles et al., 2008), disaster management (Wursthorn et al., 2004), military training (Hughes, Stapleton & Hughes, 2005), and vocational training (Fast, Gifford & Yancey, 2004). In civil engineering domain, AR has been implemented to support planning, design, construction, and maintenance phases of a project (Dunston, Wang, Bilinghurst & Hampson, 2002; Dunston & Shin, 2009), visualization of construction graphics (Behzadan & Kamat, 2005); and creation of virtual immersive job-sites to avoid safety-related concerns (Xue, Quan, Song & Wu, 2013; Henderson & Feiner, 2009). Although these implementations indicate the promising potential of AR to enhance productivity and safety in civil engineering practice, the integration of such technologies into undergraduate teaching practices has been very limited. This study aims to examine the advantages of an AR technology for learning in civil engineering programs.

Methodology

A quasi-experimental design is adopted to examine the impact of AR on teaching structural analysis concepts. The same instructor taught two sections of the course, which served as experimental and control groups. The experimental section was taught using five AR modules while the control group was taught in a traditional lecture style.

Participants

Fifty-five students enrolled in the experimental group and 18 students were enrolled in the control group. Students with missing data were taken out of the student sample size during analysis. Therefore, the sample size was narrowed to 14 students in the control group, and 38 students in the experimental group (Table 1).

Data Sources

Three main data sources for this study included tests, surveys, and classroom observations. In order to investigate if AR based pedagogical applications improve student learning, students in both the groups were given a pre-test (covering all five modules) at the beginning of the semester to measure their existing knowledge before taking the course. Students took three post-tests which was identical to the pre-test after engaging in AR activities. At the end of the course, a delayed post-test was administered to measure students' retention of the knowledge gained in the course.

Surveys

All participants completed three surveys given after the completion of an AR activity. Surveys focused on attitudes related to using the AR app and attitudes towards the class and structural engineering in general. The surveys given to the experimental group had specific questions related to the use of a certain module within the application. The control group surveys focused only on attitudes of students towards the class and structural engineering in general.

Classroom observation

In addition to collecting quantitative data, in-class observations were conducted using the Teaching Dimensions Observation Protocol (TDOP) developed by Hora and Ferrare (2013). Four observations were completed in both control and experimental classes, one observation pertaining to each time an AR activity was completed in the experimental class. Observations focused specifically on students' potential cognitive engagement in the classroom. Every two minutes of the class period, observers recorded a code relating to student cognitive engagement. Three codes were utilized to categorize cognitive engagement:

1. CNL: Making connections to own lives/specific cases: Students are given specific information that relates an abstract concept to something meaningful, or real, in students' lives. An example of this would be discussion of an on-campus structure in reference to the in-class discussion of beams.
2. PS: Problem solving: Students are asked to actively solve a problem, either through a written or verbal request. An example of this would be the professor asking students to solve the forces at a particular joint on their own, before showing the solution.

3. CR: Creating: Students are given tasks where there is not one specific solution, but rather, the outcome is open-ended. An example of this would be asking students what wind load is affected by.

Results

Preliminary results are presented in this proposal, and a complete report of findings will be included in the paper upon acceptance.

Pretest-Posttest Results

To compare results from the three pretest-posttests, the p-value test was completed. For tests one and two t-test was utilized as the data was normally distributed. For test two, the Wilcoxon rank-sum test, a nonparametric version of the t-test, was utilized to calculate the p-value, as both of the sections did not have normally distributed data. The results indicated no statistically significant difference in the growth of scores between the two sections (Table 2). The mean in the difference between pretest and posttest for the control group was higher than for the experimental group in tests one and two. The opposite was true for test three. At the time of the submission of this proposal, the analysis of the delayed post-test data has not been completed.

Observation Results

Figure 1 displays a measure of the cognitive engagement experienced by students in both the control and experimental groups over the four formal observation periods. Each time the observer noted a cognitive behavior during a 2-minute time period was noted as "one" observed behavior in the figures. As seen in Figure 2, in observation periods two, three, and four, the students in the experimental class were more cognitively engaged. While students in the control class were more engaged in CNL and PS categories for class period one, experimental students were more cognitively engaged during this period. Overall, when looking at the four class periods as a whole, students in the experimental group were more cognitively engaged. In general, during AR activities, students in the experimental class worked with peers to solve the in-class problems given. While the majority of students stayed on topic, it should be noted that at times, students became distracted by the iPads and peers, and went off topic. This was exacerbated by the large number of students in this class period.

Survey Results

Surveys given to the experimental group consisted of five parts. Part 1 asked questions relating to a specific AR activity that students completed in class. Part 2 asked students about their opinions relating to the helpfulness of the AR app, and Part 3 asked students about their opinions relating to AR in general. Part 4 asked students to rate their level of agreement with items relating to their level of engagement. Finally, Part 5 asked students to rate their level of agreement with items relating to their perception of structural engineering. Surveys given to the control group consisted of only the last two parts. In this proposal, only the results from the first survey is included.

Table 3 present the results of section one for the experimental group in regards to the first two AR activities. Students overall responded that the activity helped them in visualizing the deflection and reaction forces of beams. Students did not think that the application helped in knowing how to calculate loads as the AR application was not designed for this purpose.

Table 4 presents the results from Part 2 of the survey for the experimental group from all three surveys. Overall, students enjoyed using the AR application, and would recommend using it to their peers. More importantly, students responded strongly to questions that focused on seeing the real time response of the structures when loads were manipulated, and connecting a 2D stick model to real buildings.

Table 5 describes the responses of the experimental class to section three of the survey, which focused on student opinion of augmented reality. Unfortunately, due to weather conditions, augmented reality was only able to be used in an indoor setting. Instead of students going to the real structure on campus, the application was utilized in conjunction with large printed photos of the structure. However, despite this fact, students still responded positively towards utilizing augmented reality. The majority of students found augmented reality to be positive in learning structural analysis, and would be interested in using augmented reality in other engineering subjects. This points to the promise of not only using augmented reality in engineering undergraduate classrooms, but integrating additional technology to the undergraduate curriculum in order to enhance the student learning experience.

Table 6 and Table 7 present the results of parts three and four of the survey for both the experimental and control groups. In both tables, the mean values from questions are shown, where the higher the mean indicates students agreeing with the statement more strongly. In looking at Table 6, over the semester, there was not a clear pattern in the results from the surveys when comparing the experimental and control groups. While on survey two the experimental group responded more strongly to some questions, on survey three the opposite was true. However, in both questions five and six, students in the experimental group responded that they felt more connected to both their peers and the professor in the experimental group, as compared to the control group. This could be due to the increased teamwork and interaction among students when using the AR in the experimental classroom. Overall, students did respond that they were more engaged in one class than another, referring to responses on questions eleven and twelve. In looking at Table 7, student perceptions related to questions fluctuated over the semester. Interestingly, students in the experimental group found structural engineering less interesting than those students in the control group, as shown by question one. This being said, the same students were more excited in the experimental group to take another structural engineering course than those students in the control group. However, these differences are relatively minor. It is worth noting that students in the experimental class did feel more confident in their structural engineering skills than those in the control group, as indicated by responses to questions two and five. While the use of AR may not have changed student's prospective interests, it may have led to an increased understanding of and confidence in topics in students in the experimental group.

Conclusion and Significance of the Study

The goal of this study was to implement and asses an augmented reality application in an undergraduate education setting focusing on structural analysis. Findings from the research suggest that although AR may not yet have a statistically significant impact on the learning of students, it does positively enhance the student learning experience. Specifically, students found that AR helped them to contextualize typical two-dimensional stick models taught in structural analysis in a real-world, three-dimensional context. On average, students were more cognitively engaged in activities when using AR than those students who were taught in a traditional manner. Additionally, students responded positively on surveys given throughout the semester. While data from surveys does not dictate the learning potential associated with a technology, it may help researchers understand what students are excited about, and where they place value in their education.

Tables and Figures

Table 1. *Participant information*

Group	Gender		Program			Year of Study		
	Male	Female	Construction	Civil	Other	Junior	Senior	Other
Control (N=14)	67%	33%	22%	72%	6%	83%	11%	4%
Experimental (N=38)	78%	22%	40%	58%	2%	80%	16%	4%

Table 2. *Pretest to posttest comparison between groups*

Test	**Group**	*n*	*M*	*SD*	*DF*		*t*	*p*
Test 1 (t-test)	Control	14	3.71	2.30	51		-0.76	0.45
	Experimental	38	3.13	2.79				
Test 2 (Wilcoxon rank-sum)		*n*	*M*	*SD*	*Score Sum*	*Score Mean*	*t*	*p*
	Control	14	2.79	2.39	423	30.21	0.28	0.28
	Experimental	38	1.58	3.89	955	25.13		
Test 3 (t-test)		*n*	*M*	*SD*	*DF*		*t*	*p*
	Control	14	0.86	2.48	51		0.62	0.54
	Experimental	38	1.34	2.56				

Table 3. *Part 1 survey results for experimental group, beam and load AR activity.*

1. Please rate how helpful the Beam and Load (Skywalk and Campanile) AR activity was for you to:	**Mean**	**SD**
1. Visualize the structural components of a building	4.35	0.98
2. Understand the difference in dead, live, wind, seismic loads	4.22	0.99
3. Understand how to calculate loads	3.69	1.13
4. Analyze a simply supported beam	4.31	0.92
5. Analyze a cantilever beam	4.22	0.96
5. Visualize how a beam deflects under certain loads	4.41	1.00
6. Visualize the reactions of a beam caused by certain loads	4.41	1.00
7. Draw the deflection shape of a beam	4.00	1.15
8. Understand equilibrium in beams	4.00	1.00

5=Very helpful, 1=Somewhat helpful, 3=Neutral, 2=Somewhat unhelpful, 1=Very unhelpful

Table 4. *Part 2 survey results compiled for experimental group.*

	Survey 1		**Survey 2**		**Survey 3**	
2. Please rate your level of agreement for each of the statements related to using the AR app.	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**
1. Seeing the hidden structure of a building on campus through the AR app helped me visualize the connection between a model and the real building	4.31	0.73	4.11	0.65	4.28	0.67
2. Using the AR app allowed me to solve structural analysis problems on my own	4.06	0.83	3.62	1.00	3.70	1.03
3. Manipulating the magnitude of the load in the app helped me understand how the load influenced the structural behavior (i.e. deflection shape, reaction forces)	4.38	0.7	4.38	0.54	4.25	0.80
4. Being able to manipulate the location of the load in the app helped me understand the effect that the load location has on structural behavior (i.e. deflection shape, reaction forces)	4.41	0.55	4.35	0.62	4.18	0.80
5. It was fun to use the AR app to see the hidden structures of a building on campus	4.41	0.65	4.32	0.81	4.23	0.85
6. The AR system allows learning by playing	4.28	0.72	4.24	0.91	4.08	0.88
7. I enjoyed using the AR app	4.28	0.80	4.14	0.85	4.08	0.88

8. Learning through the AR app was boring	2.58	1.43	2.75	1.38	2.65	1.28
9. Using the AR app would facilitate better understanding of complex engineering concepts.	4.19	0.68	4.08	0.75	4.00	0.87
10. I would like to use the AR app in the future if I had the opportunity.	4.19	0.92	4.14	0.99	4.03	0.91
11. I would like to recommend this AR app to my fellow students.	4.16	0.87	4.14	0.83	3.98	0.99

Table 5. *Part 3 survey responses compiled for experimental group.*

	Survey 1		**Survey 2**		**Survey 3**	
3. Please rate your opinions about using AR in general.	**Avg.**	**SD**	**Avg.**	**SD**	**Avg.**	**SD**
1. The use of AR makes learning more interesting	4.34	0.59	4.27	0.72	4.10	0.77
2. I believe the use of AR improves learning in a classroom environment.	4.28	0.80	4.03	0.85	4.10	0.86
3. I believe using an AR app to learn structural analysis concepts is a good idea.	4.31	0.73	4.22	0.70	4.18	0.70
4. I would like to use an AR app to learn other related topics in Structural Analysis.	4.28	0.67	4.22	0.87	4.10	0.89
5. I would like to use an AR app to learn other engineering subjects.	4.16	0.79	4.30	0.77	4.18	0.80

Table 6. *Part 4 survey results compiled for experimental and control groups.*

	Survey 1		**Survey 2**		**Survey 3**		**Average**	
4. Please rate your level of agreement with the following items related to your level of engagement in this class.	**E**	**C**	**E**	**C**	**E**	**C**	**E**	**C**
1. I looked forward to going to this class.	4.03	3.92	4.00	3.92	3.78	4.17	3.94	4.00
2. This class was interesting.	4.16	4.25	4.22	4.17	3.88	4.08	4.08	4.17
3. I felt engaged during this class.	4.03	4.00	4.16	3.92	3.88	4.00	4.02	3.97
4. The tasks required of me in this class were valuable to me.	4.06	4.08	4.30	4.08	3.80	4.00	4.05	4.06
5. I felt connected to other students in this class.	4.00	3.50	4.03	3.42	3.98	3.75	4.00	3.56

6. I felt connected to my instructor in this class.	4.03	3.92	3.97	3.92	3.85	3.75	3.95	3.86
7. The information in this class was useful.	4.16	4.33	4.30	4.33	4.08	4.17	4.18	4.28
8. We discussed real-world problems in class.	4.38	4.42	4.24	4.17	3.93	4.08	4.18	4.22
9. We solved open-ended problems in this class.	3.84	4.00	3.97	3.92	3.70	4.00	3.84	3.97
10. I frequently took notes during this class.	3.88	4.00	4.22	4.25	4.00	4.50	4.03	4.25
11. I asked questions during this class.	3.28	3.17	3.24	3.25	3.15	3.33	3.22	3.25
12. I responded to questions in this class	3.50	3.67	3.59	3.50	3.25	3.50	3.45	3.56

Table 7. *Part 5 survey results compiled for experimental and control groups.*

	Survey 1		**Survey 2**		**Survey 3**		**Average**	
5. Please rate your level of agreement with the following items related to your perceptions of structural engineering.	**E**	**C**	**E**	**C**	**E**	**C**	**E**	**C**
1. Structural engineering is interesting.	4.13	4.33	3.95	4.33	3.82	4.08	4.13	4.25
2. I am confident in my skills related to structural engineering.	4.03	3.50	3.97	3.50	3.69	3.50	4.03	3.50
3. I am excited about becoming an engineer.	4.41	4.33	4.43	4.33	4.15	4.33	4.41	4.33
4. I would be excited to take another structural engineering course.	3.94	3.75	3.81	3.75	3.64	3.42	3.94	3.64
5. I felt intimidated by what was required of me in this course.	3.25	3.08	2.76	3.25	3.23	3.42	3.25	3.25
6. I would be interested in pursuing a career related to structural engineering.	3.69	3.83	3.46	3.92	3.41	3.67	3.69	3.81

References

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *Computer Graphics and Applications, IEEE*, *21*(6), 34-47.

Behzadan, A. H., & Kamat, V. R. (2005). Visualization of construction graphics in outdoor augmented reality in M.E. Kuhl, N.M. Steiger, F.B. Armstrong, and J.A. Joines (eds) *Proceedings of the 2005*

Winter Simulation Conference pp. 1914-1920.
Davalos, J. F., Moran, C. J., & Kodkani, S. S. (2003). Neoclassical active learning approach for structural analysis. In *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition*.
Dunston, P., Wang, X, Billinghurst, M. & Hampson, B. (2002) Mixed reality benefits for design perception. Proceedings of 19th International Symposium on Automation and Robotics in Construction(ISARC 2002), NIST Special Publication 989 (2002), pp. 191-196 National Institute of Standards and Technology (NIST), Washington D.C.
Dunston, P. S., & Shin, D. H. (2009). Key areas and issues for augmented reality applications on construction sites. *Mixed Reality In Architecture, Design And Construction*, 157–170. http://doi.org/10.1007/978-1-4020-9088-2
Fast, K., Gifford, T., & Yancey, R. (2004). Virtual training for welding. *ISMAR 2004: Proceedings of the Third IEEE and ACM International Symposium on Mixed and Augmented Reality*, (Ismar), 298–299. http://doi.org/10.1109/ISMAR.2004.65
Henderson, S. J., & Feiner, S. (2009). Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. *Science and Technology Proceedings - IEEE 2009 International Symposium on Mixed and Augmented Reality, ISMAR 2009*, 135–144. http://doi.org/10.1109/ISMAR.2009.5336486
Hora, M. T., & Ferrare, J. J. (2013). Instructional systems of practice: A multidimensional analysis of math and science undergraduate course planning and classroom teaching. *The Journal of Learning Sciences*, *22*(2), 212–257.
Hughes, C. E., Stapleton, C. B., Hughes, D. E., & Smith, E. M. (2005). Mixed reality in education, entertainment, and training. *IEEE Computer Graphics and Applications*, *25*(6), 24–30. http://doi.org/10.1109/MCG.2005.139
Quarles, J., Lampotang, S., Fischler, I., Fishwick, P., & Lok, B. (2008). A mixed reality approach for merging abstract and concrete knowledge. *Proceedings - IEEE Virtual Reality*, (1), 27–34. http://doi.org/10.1109/VR.2008.4480746
Teng, J. G., Song, C. Y., & Yuan, X. F. (2004). Fostering creativity in students in the teaching of structural analysis. *International Journal of Engineering Education*, *1*(20), 96–102.
Wursthorn, S., Coelho, A. H., & Staub, G. (2004). Applications for mixed reality. In *ISPRS Congress* (pp. 12–23). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.133.7732&rep=rep1&type=pdf
Xue, H., Quan, H., Song, X., & Wu, M. (2013). Construction of simulation environment based on augmented reality technique. In *Asiasim*. Springer.